GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT INITIATION

Date: March 21, 1975

Project Title: Effect of Polymer Additives on Turbulent Blood Flow

Project No: E-16-666

Principal Investigator: Dr. Don P. Giddens

Sponsor: DHEW/PHS/NIH -- National Heart & Lung Institute, Bethesda, Maryland

Agreement Period: From 1/1/75 Until 12/31/76*

Type Agreement: Grant No. 2 RO1-HL15519-03 CVB

Amount: $62,268 PHS Funds (E-16-666)
4,331 GIT Contrib. (E-16-355)
$66,599 TOTAL

Reports Required: Terminal Progress Report

Sponsor Contact Person (s):

Peter L. Frommer, MD.
Assoc. Director for Cardiology
National Heart & Lung Institute
Division of Heart & Vascular Diseases
DHEW, PHS, NIH
Bethesda, Maryland 20014

*See Project No. E-16-630 for 01 year funding, and E-16-643 for 02 Year funding

Assigned to: School of Aerospace Engineering

COPIES TO:

- Principal Investigator
- School Director
- Dean of the College
- Director, Research Administration
- Director, Financial Affairs (2)
- Security Reports-Property Office
- Patent Coordinator
- Library
- Rich Electronic Computer Center
- Photographic Laboratory
- Project File
- GTRI
- Other

RA-3 (6-71)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Posted 8/24/77

Date: June 20, 1977

Project Title: "Effect of Polymer Additives on Turbulent Blood Flows."

Project No: E-16-666

Project Director: Dr. D. P. Giddens

Sponsor: DHEW, Public Health Service

Effective Termination Date: 12/31/76

Clearance of Accounting Charges: 12/31/76

Grant/Contract Closeout Actions Remaining:

- x Final Invoice
- x Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other _____

Assigned to: Aerospace Engineering (School/Laboratory)

COPIES TO:

- Project Director
- Division Chief (EES)
- School/Laboratory Director
- Dean/Director—EES
- Accounting Office
- Procurement Office
- Security Coordinator (OCA)
- Reports Coordinator (OCA)
- Library, Technical Reports Section
- Office of Computing Services
- Director, Physical Plant
- EES Information Office
- Project File (OCA)
- Project Code (GTRI)
- Other _____

CA—4 (3/76)

FINAL PROGRESS REPORT

Grant Number: HL15519

Period Covered: 1/1/73 through 12/31/76

Principal Investigators: D. P. Giddens and R. F. Mabon

Institution: School of Aerospace Engineering, Georgia Institute of Technology

Project Title: Effect of Polymer Additives on Turbulent Blood Flow

Two related, but distinctively separate, problems in hemodynamics were studied under the subject grant. The first was an investigation into the behavior of the flow field during angiographic injections, while the second was a study of the characteristics of flow in the neighborhood of localized arterial stenoses. Both theoretical analyses and experimental measurements were included in the research program, and a large effort was placed on the acquisition and improvement of instrumentation for measurement of fluid velocity.

Results of the study included the following:

1. A theoretical model for fully turbulent angiographic injections was developed and coded for solution on a digital computer. The model is a numerical representation of turbulent boundary layer equations and is capable of calculating velocity profiles, pressures, shear stresses, and turbulence kinetic energy.

2. In vitro experiments with a hot film anemometer in modeled angiographic injections were completed for a fully turbulent case and the measurements of velocity profiles were compared with the theoretical calculations. Agreement was very good.

3. Modeled experiments of angiographic injections in which a drag reducing polymer is present indicate that the polymer promotes mixing of catheter fluid with the outer flow at high catheter Reynolds numbers. At lower catheter Reynolds numbers the polymer tends to prevent turbulence within the catheter; and the injectant fluid emerges as a coherent laminar stream which does not disperse readily. However, the addition of a wall "trip", or small ring, within the catheter to produce flow instabilities just prior to the exit improves the mixing characteristics considerably. The net result is that, provided a tripping mechanism is introduced, the addition of small amounts of drag reducing polymer improves the mixing of the catheter fluid with the outer flow in the in vitro studies. Additionally, the tripping device should be of value in improving the mixing characteristics of injections made at low flow deliveries.

4. The hot film anemometer probe was inadequate for providing accurate in vivo measurements of angiographic injections due to dissimilarities

in the thermal and viscous properties of blood and contrast media.

5. Calculations demonstrate that certain angiographic injection configurations create wall shear stresses which are sufficiently high to strip away endothelial cells from the arterial surface.

6. Experiments were conducted to measure instantaneous velocities distal to localized subtotal vascular stenoses in both animal and in vitro experiments. When the stenosis is moderate to severe (50 percent or greater reduction in cross-sectional area), results demonstrate that the flow is very turbulent in the neighborhood immediately distal to the constriction. Mild stenoses (20-25 percent area reduction) were shown to create marked disorder in distal velocity waveforms during a period near peak systolic velocity.

7. Mathematical methods for examining flow disorder were developed and applied to the in vivo data. Several techniques for characterizing this disorder show promise for detecting the presence of arterial stenoses. In particular, a comparison of turbulence energy spectra during the acceleration phases of systole was a very good indication of the existence of mild stenoses.

Thus, the research has established that relatively large wall shear stresses may be encountered during angiographic injections, and techniques for reducing the hazards of these injections have been delineated. The mixing of catheter fluid with the coflowing vessel stream is improved with the addition of drag reducing polymer, but it is not clear at this time whether the improvement is sufficient to be of significant clinical value. Finally, analysis techniques have been developed which, when applied to acute studies in the dog aorta, demonstrate that flow disorder is an indication of the presence of mild vascular constrictions. If this finding can be demonstrated to be valid in human studies and if the required measurements can be obtained noninvasively, then these results may be of great importance in the early detection of localized atheroma.

List of Publications Already in Print

1. "Experimental Observations of the Velocity Field Distal to Partial Occlusions in Arteries," Recent Advances in Engineering Sciences, Vol. 6, pp. 47-54, 1976; by D. P. Giddens, R. F. Mabon, R. A. Cassanova, R. K. Menon, and J. Chandler.

2. "Measurements of Disordered Flows Distal to Subtotal Vascular Stenoses in the Thoracic Aortas of Dogs," Circulation Research, Vol. 39, No. 1, pp. 112-119, 1976; by D. P. Giddens, R. F. Mabon, and R. A. Cassanova.

Manuscripts Submitted for Publication

1. "Analysis of Disorder in Pulsatile Flows with Application to Poststenotic Blood Velocity Measurements in Dogs," submitted to Journal of Biomechanics, October 1976; by D. P. Giddens, A.M.A. Khalifa, and R. F. Mabon. Review was favorable, minor changes were requested.

Ph.D. Theses Published

1. "An Experimental Investigation of Steady and Pulsatile Flow Through Partial Occlusions in a Rigid Tube," R. A. Cassanova, 1975.

2. "A Study of Ducted Jets Including the Effects of Dilute Polymer Solutions", R. K. Menon, 1976.

Ph.D. Theses in Preparation

1. "Steady Laminar and Turbulent Flow Through Vascular Stenosis Models," M. D. Deshpande. To be published in April, 1977.

2. "Fluid Dynamic Modelling of Angiographic Injections: Possible Improvement Through the Use of Drag Reducing Polymers" W. A. Carpenter. To be published in Summer, 1977.

3. "The Role of Flow Disorder in the Noninvasive Detection of Atherosclerosis", A. M. A. Khalifa. To be published in Summer, 1977.

Papers Presented

1. D. P. Giddens, R. F. Mabon, R. A. Cassanova, R. K. Menon and J. Chandler; "The Velocity Field Distal to Partial Occlusions in Arteries," presented at the Tenth Anniversary Meeting of the Society of Engineering Science, Raleigh, N. C., November 4-6, 1973.

2. D. P. Giddens, R. A. Cassanova and R. F. Mabon; "The Velocity and Sound Fields Distal to Partial Occlusions in Pulsatile Tube Flow," presented at the 77th Annual Meeting of the American Institute of Chemical Engineers, Pittsburg, Penn., June 2-5, 1974.

3. R. K. Menon, D. P. Giddens and R. F. Mabon; "The Turbulent Flow Field of Modelled Angiographic Injections," presented at the 27th Annual Conference on Engineering in Medicine and Biology, Philadelphia, Penn., October 1974.

4. M. D. Deshpande, D. P. Giddens and R. F. Mabon; "Steady, Laminar Flow Through Partial Stenoses," presented at the 11th Annual Meeting of the Society of Engineering Science, Duke University, Durham, N. C., November 1974.

5. D. P. Giddens, R. F. Mabon, and R. A. Cassanova; "Turbulence Measured Distal to Subtotal Vascular Stenoses - In Vivo", presented at ASME Symposium on Biomechanics, Rensselaer Polytechnic Institute, Troy, New York, June 1975.

Papers Presented (continued)

6. R. A. Cassanova, D. P. Giddens, and R. F. Mabon; "A Comparison of Stenotic Fluid Dynamics in Steady and Pulsatile Flow," presented at ASME Symposium on Biomechanics, Rensselaer Polytechnic Institute, Troy, New York, June 1975.

7. R. A. Cassanova, D. P. Giddens, and R. F. Mabon; "Pulsatile Flow Through Axisymmetric Stenoses in Rigid Tubes," presented at 28th Annual Conference on Engineering in Medicine and Biology, New Orleans, La., September 1975.

8. D. P. Giddens, R. F. Mabon, A. M. A. Khalifa, and R. A. Cassanova; "Measurement of Flow Disorder Created by Mild Stenoses," 3rd International Exhibit and Congress for Medical Electronics and Bioengineering, Basel, Switzerland, June 1976.

9. R. A. Cassanova and D. P. Giddens; "Fluid Dynamic Correlations of Modelled Stenotic Flows," presented at 11th International Conference on Medical and Biological Engineering, Ottawa, Canada, August 1976.

10. D. P. Giddens, R. A. Cassanova, R. F. Mabon, and A. M. A. Khalifa; "Analysis of Disordered Flows Created by Vascular Stenosis," presented at 11th International Conference on Medical and Biological Engineering, Ottawa, Canada, August 1976.

Invited Presentation

1. "Measurements of Turbulent Fluctuations Downstream of Vascular Stenosis", presented at Laboratoire de Biorheologie et d'Hydrodynamique Physiologique, Universitê Paris VII, Paris, France, June 1976; D. P. Giddens.

E-16-666

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

OFFICE OF
THE DIRECTOR OF
FINANCIAL AFFAIRS

August 11, 1977

National Institutes of Health
Division of Financial Management
Grants Section, FAAB
Westwood Building, Room 405
5333 Westbard Avenue
Bethesda, Md. 20014

Gentlemen:

Enclosed is the Final Report of Research Grant Expenditures for Grant Number 5 ROI HL15519-04 covering the period January 1, 1976 through December 31, 1976.

If you have questions or desire additional information, please let us know.

Sincerely yours

Evan Crosby
Associate Director of
Financial Affairs

EC/bs
Encl.
cc: Dr. D. P. Giddens
Mr. E. E. Renfro
Mr. A. H. Becker
File: E-16-666

*U.S. GOVERNMENT PRINTING OFFICE: 1973 — 730-517

Department of Health, Education, and Welfare

Grant No: 5 ROI HL15519-04

NAME AND ADDRESS OF GRANTEE INSTITUTION

Georgia Institute of Technology
Atlanta, Georgia 30332

PHS ACCOUNT NO.

TRANSACTION NO. (08)R1HL15519B

INSTITUTIONAL ID NO. E-16-666

DATE OF THIS REPORTING PERIOD: FROM 1-1-76 TO 12-31-76

PROJECT PERIOD: FROM 1-1-75 TO 12-31-76

[X] CHECK IF FINAL REPORT

1. Expenditures of DHEW Funds for this Report Period

a. Personnel	$ 38,951.97	h. Alterations and renovations	
b. Consultant services	218.00	i. Other	
c. Equipment			
d. Supplies	4,357.87	j. Total direct costs	45,070.47
e. Travel, domestic	1,042.63	k. Indirect costs: Rate 68 % [X] S&W [ ] TDC	
f. Travel, foreign	500.00	Base $ 37,170.00	25,275.60
g. Patient care costs		l. TOTAL	$ 70,346.07

2. Expenditures from Prior Periods (previously reported)	62,779.51
3. Cumulative Expenditures	133,125.58
4. Total Amount Awarded - Cumulatively	134,458.00
5. Unexpended Balance (Item 4 less Item 3)	1,332.42
6. Unliquidated Obligations	-0-
7. Unobligated Balance (Item 5 less Item 6)	1,332.42
8.a. Cost Sharing Information - Grantee Contribution This Period	4,872.62
b. % of Total Project Costs (Item 8a divided by total of Items 1 and 8a)	% 6.5
9.a. Interest/Income (enclose check)	
b. Other Refundable Income (enclose check)	

10. Remarks

I hereby certify that this report is true and correct to the best of my knowledge, and that all expenditures reported herein have been made in accordance with appropriate grant policies and for the purposes set forth in the application and award documents.

Evan Crosby — August 11, 1977

SIGNATURE OF INSTITUTION OFFICER — DATE

Associate Director of Financial Affairs

HEW-489 (REV. 9/67)

REPORT OF RESEARCH GRANT EXPENDITURES

BUDGET BUREAU NO. 122-R0119